THE ABUNDANCE, DISTRIBUTION, AND BIOLOGY OF PLANKTON IN LAKE MICHIGAN WITH THE ADDITION OF A RESEARCH SHIPS OF OPPORTUNITY PROJECT

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ABSTRACT

This report summarizes the results obtained from a study on the abundance, distribution, and biology of plankton in Lake Michigan as well as from a Research Ships of Opportunity cruise.

Modifications needed to adapt the Continuous Plankton Recorder for use in the Great Lakes are presented in detail. The major change from the procedure used in the marine Recorder survey on the plankton of the North Atlantic is the use of a finer silk for filtering.

A detailed presentation is also made of the scientific results obtained during a cruise aboard a Research Ship of Opportunity from Detroit, Michigan to Bilboa, Spain. Studies were made on the changes in composition of the zooplankton community as well as in the amounts of particulate organic matter and dissolved organic matter encountered during this cruise. The diversity and quantity of microcrustaceans were found to be greater in the lakes than in the comparable marine environments. Particulate and dissolved organic matter followed very similar trends in relative abundance and were especially high in western Lake Erie and at the mouth of the St. Lawrence River.

[1] We wish to acknowledge the contribution of Mrs. Sharon C. Czaika, who assisted with all phases of the work and who carried out much of the work with the diaptomids; and of Mrs. Jeanne Rose, who carried out most of the analyses of the samples from the Research Ships of Opportunity cruise. Also we would like to express thanks to the Edinburgh Oceanographic Laboratory of the Scottish Marine Biological Association and especially the Director, R. S. Glover, for great assistance both in the work using Continuous Plankton Recorders in the Great Lakes and in analyzing our marine Recorder tow.

SUMMARY

This is the final report on ONR Project NR 104-818, Contract Nonr-1224 (53), which was conducted from March 1, 1965 to February 29, 1968 with a continuation to May 31, 1968. Objectives of the study are listed below, with a brief summary of the results. Some results from this study have been published, as indicated by the bibliography; therefore emphasis in this report will be on unpublished data.

Objective 1

To determine the adjustments needed to adapt the Continuous Plankton Recorder for use in conducting a survey of the plankton of the Great Lakes.

Results: It has been determined that the Recorder should be adjusted in the following ways for use in the Great Lakes: (1) It should be loaded with #7 (82 meshes/inch) silk bolting cloth. Considering both catching ability and filtering efficiency, this mesh size was found to be somewhat preferable to #4 (62 meshes/inch) silk and much preferable to #10 (109 meshes/inch) silk. The Great Lakes plankton large enough to be retained by this silk is mostly limited to crustaceans. (2) It was determined that the optimum speed for silk to pass through the Recorder in Lakes Michigan and Huron is the same as in the marine Recorder survey, approximately 4 inches of winding for every 10 miles of towing. For Lake Erie the plankton is much more abundant and the winding speed should be much faster. (3) As in the marine survey, the optimum towing depth for the Recorder in the Great Lakes is 10 m. The plankton at this depth is representative of the upper layers and shows a comparatively low amount of variability in abundance throughout the upper 10 m.

Objective 2

To determine and explain the distribution patterns of ten Great Lakes calanoid copepods.

Results: The geographical distribution of the ten calanoid copepods was determined by a synthesis of previously published information and the collection of new data. Six species occur in each of the Great Lakes: *Diaptomus ashlandi*, *D. minutus*, *D. oregonensis*, *D. sicilis*, *Epischura lacustris*, and *Limnocalanus macrurus*. *Senecella calanoides* occurs in all the lakes but Erie; *Eurytemora affinis* in Lakes Ontario, Erie, and Michigan; *D. siciloides* in Ontario and Erie; and *D. reighardi* only in Erie. *D. sicilis* and *L. macrurus* are more abundant in the upper lakes, and *D. oregonensis* is more abundant in the lower lakes.

A comparison of the relative abundance of diaptomids in Lake Michigan in 1954-55, 1964 and in Lake Erie in 1956-57 shows that *D. oregonensis* was most abundant in Lake Erie in 1956-57, and *D. sicilis* in Lake Michigan in 1954-55. The season of maximum abundance of a species was generally earlier in Lake Erie than in Lake Michigan.

Detailed results of this study are presented in Robertson (1966).

Objective 3

To develop a method for identifying the sex and stage of copepodites of six species of Great Lakes diaptomids.

Results: Means of identifying the Great Lakes diaptomid copepodids were developed by comparing the armature of all the appendages from each copepodid stage of each species. Quite a number of differences in armature were noted that varied only with stage and not with either species or sex. A few differences in armature were noted that varied within a given stage as to species but not as to sex. Finally, several differences were noted within

the last three stages that varied by sex but not species. The differences noted above were presented in chart form and combined in a key to provide means for identifying the Great Lakes diaptomid copepodids to species, stage, and, for the last three stages, sex.

Results of this study have been reported by Czaika and Robertson (1968).

Objective 4

To demonstrate that data of substantial scientific value can be obtained using a Research Ship of Opportunity.

Results: A commercial vessel was used to gather biological samples on its regular cruise from Detroit, Michigan to Bilboa, Spain. During the cruise, samples were gathered for measurement of the amounts of particulate organic matter and of dissolved organic matter, and for determination of the composition of the zooplankton community. Some of the results from this cruise have been used in comparing the distribution of organic matter in the St. Lawrence Great Lakes. These results have shown that the concentration of organic matter in the different lakes is closely correlated with the concentration of total dissolved solids and so with the relative state of eutrophication. These studies have shown that Research Ships of Opportunity can be used in either fresh or salt water and that the results obtained from a Research Ships of Opportunity project can be of substantial scientific interest.

The experiences gathered in planning, preparing for, and carrying out the Research Ships of Opportunity project are presented in Robertson (1967), the comparison of distribution of organic matter in the Great Lakes in Robertson and Powers (1967).

Objective 5

To study the changes in the composition of the zooplankton community

and in the amounts of particulate organic matter and dissolved organic matter encountered in going from the fresh water of the Great Lakes out the St. Lawrence River and the Gulf of St. Lawrence to the salt water of the open Atlantic Ocean.

Results: The zooplankton communities in the upper waters of Lakes Ontario and Erie were found to be more diverse than the communities in comparable environments in the North Atlantic. The lakes, especially Lake Erie, also had greater numbers of zooplankters per cubic meter.

Particulate organic matter and dissolved organic matter showed very similar trends in abundance during the freshwater part of the cruise. Unfortunately, technical problems made it impossible to measure these parameters during the saltwater part. Amounts of particulate organic matter were found to be especially high in western Lake Erie and at the mouth of the St. Lawrence. It is suggested that these high values may be related to favorable conditions for phytoplankton production in these two environments.

Detailed results of this study are presented later in this report.

Objective 6

To initiate a survey of the horizontal and seasonal distribution of the plankton in Lake Michigan.

Results: A survey of the plankton of Lake Michigan, similar to the marine plankton survey carried out in the North Atlantic by the Scottish Marine Biological Association, has been initiated. Six tows of a Continuous Plankton Recorder have been made between Muskegon, Michigan and Milwaukee, Wisconsin. These samples are still being analyzed, and the results of this study will be published later.

APPLICABILITY OF THE CONTINUOUS PLANKTON RECORDER

TO PLANKTON STUDIES IN LAKE MICHIGAN

The Continuous Plankton Recorder, initially developed by Hardy (1939), has been used extensively to study the plankton of the North Sea and North Atlantic (Glover 1962). It is an instrument used to collect plankton during the normal passage of commercial vessels. It samples at a depth of 10 m below the surface. The Recorders are adjusted in such a way as to maintain this depth when being towed within a range of speeds from 10 to 18 knots.

Water enters the front of the Recorder through a 0.5-inch square opening and flows into a 2 by 4-inch water tunnel. A continuously moving band of bolting silk (usually 60 meshes/inch) crosses this tunnel and filters out the plankton. As the Recorder is towed, a propeller, exposed to the flow of water, drives a winding mechanism that pulls the silk through the tunnel at a predetermined rate. After emerging from the tunnel, the silk is covered by a second band of silk to hold the plankton in place, and the two bands are wound onto a storage spool in a tank containing formalin.

A long-term survey of the plankton of the North Sea and North Atlantic is being carried out by the Scottish Marine Biological Association, Edinburgh Laboratory, using this instrument. The survey began in 1931 and, with a break during the Second World War, has continued to the present. Recorders are towed roughly once a month over a series of standard routes by commercial vessels and Ocean Weather Ships. For this survey the silk winding rate is adjusted so that approximately 3 m^3 of water are filtered for every 10 miles of towing.

After towing, the Recorders are returned to the Edinburgh Laboratory where the silks are unrolled and cut into 4-inch blocks, each of which

represents approximately 10 miles of sampling. Colebrook (1960) has summarized the most recent methods used to analyze these blocks. Estimates of the numbers of the different plankters present are obtained, and these data have been used as the basis of a large number of studies on the distribution, systematics, and general ecology of the plankters of the area.

It would be very desirable to be able to carry out similar studies on the plankton of the Great Lakes. The pelagic community is obviously an immensely important part of the Great Lakes ecosystem. However, the difficulties in collecting large numbers of samples in a regular manner have largely precluded detailed studies on the offshore plankton of the Great Lakes. Primarily, the lack of research ships and their expense when available have prevented the needed long-term, geographically extensive studies.

The objective of the present study was to adapt the Continuous Plankton Recorder for sampling in the Great Lakes, so it would provide, as it has in the Atlantic, the means by which a relatively inexpensive survey of the plankton could be conducted. A large number of commercial vessels ply the Great Lakes, so the opportunity to develop an extensive plankton survey is present.

Before the initiation of this contract, the principal investigator spent two years in the Edinburgh Laboratory becoming thoroughly familiar with the use of the Recorder and methods for analyzing the samples it collects. It was concluded that adaptation of the Recorder to plankton sampling in the Great Lakes environment would require consideration of the following problems: (1) selection of a silk with a suitable mesh for use in sampling the Great Lakes plankton, (2) determination of the optimum speed at which the silk should pass through the Recorder, and (3) determination of the optimum depth for towing the Recorder.

Selection of a Suitable Silk

The marine plankton survey uses Recorders equipped with bolting silk having 60 meshes per inch. It is assumed that this silk retains a major proportion of the larger organisms, such as Copepoda, Cladocera, Pteropoda, and Chaetognatha, and enough of the smaller forms to indicate their areas of greater abundance. The Great Lakes plankton has a much smaller number of major taxonomic groups than the marine plankton. Only the crustaceans and the relatively rare fish larvae approach the size of the larger marine zooplankters. It was decided that, for use in the Great Lakes, it would only be possible for Recorder sampling to provide a representative picture of the distribution of the crustaceans. For the smaller forms such as rotifers, protozoans, and phytoplankters, the best that could be expected would be data similar to that obtained for the smaller marine forms.

In adapting the Recorder for use in the Great Lakes, initial consideration was given to continuing the use of the 60 meshes per inch silk. However, as the planktonic crustaceans in the Great Lakes tend to have a smaller average size than their North Atlantic relatives, and as Robertson (in press) has shown that many of the young stages of the smaller species even in the North Atlantic escape this silk, it was decided to investigate the possibility of using a finer silk.

To study the feasibility of using a finer silk, a series of tests was conducted to compare the filtering and plankton-catching abilities of several silks. Dufour silk bolting cloths with 62 (#4), 82 (#7), and 109 (#10) meshes per inch were compared. No bolting cloth exactly comparable to the 60 meshes per inch silk used in the marine survey was available, but it was felt that the #4 silk was close enough to be considered the same for all practical purposes.

Double bands of silk were prepared of each of the three mesh sizes as described by Hardy (1939). They were made of sufficient length for two hours of towing. The three bands, one of each mesh size, were then glued together and loaded in a Recorder. This Recorder was towed for two hours so a sample was obtained using the first mesh size. After two hours, the Recorder was brought aboard and the joined bands of silk wound through the Recorder until the next mesh size was ready for towing. The procedure was repeated so a sample with the second mesh size was obtained and after this a sample with the third mesh size.

This type of sampling was carried out on several different dates. The tows were started a short distance out into Lake Michigan off the piers at Grand Haven, Michigan. The tow with the first silk was made to the north parallel to the shore for two hours, that with the second silk back toward Grand Haven for two hours, and that with the third silk once again north for two hours. Finally, the Recorder, but without any silk, was towed back to Grand Haven for two hours. The order in which the different mesh sizes was towed was altered for each series of tows so that a certain mesh size was not always towed in the same direction.

The Recorder was fitted with a flow meter to monitor the relative amounts of water passing through in two hours time using each of the silks and with no silk in place. This flow meter was attached over the water exit of the Recorder with a canvas sleeve that forced all the water leaving the instrument to flow through the meter.

Meter readings for each date are presented in Table 1. It can be seen at once that even with no silk in place the meter readings vary for the different dates. These variations probably reflect the effect of environmental conditions on the flow characteristics on different dates.

TABLE 1. Flow meter readings for two hours of towing with #4 (62 meshes/inch), #7 (82 meshes/inch), and #10 (109 meshes/inch) silks and no silk in the Recorder.

Date	Number of silk			No silk
	#4	#7	#10	
13-IX-65	8240	5705	6210	8540
5-X-65	7660	6878	7175	7670
10-XI-65	6345	6520	6650	7050
22-IV-66	6325	6250	5915	6770
30-VI-66	5430	5560	5260	7110

As expected, the reading for the tow when no silk was in place was always the highest for a certain date. Usually the readings were somewhat lower than this but within 10 to 12 percent of the "no silk" one. For the June towing all three silks show much lower readings, while for the September towing only the readings for the #7 and #10 silks are much lower.

These much lower readings probably indicate clogging of the silks with small organisms, mostly phytoplankton. Clogging of this type is common when sampling plankton with bolting cloth in nets or other devices. The chance of clogging increases as the bolting cloth gets finer, and this is one of the major reasons the marine Recorder survey does not use a silk finer than 60 meshes per inch. Obviously, if the silk clogs, the filtering efficiency is decreased and the number of organisms caught is decreased.

From these results it appears that clogging of Recorder silks of the mesh sizes used here will be a problem only part of the time in the Great Lakes, but that at times clogging will decrease the filtering efficiency by as much as 30 to 40%.

On one of the two dates when clogging was observed, the #4 silk did not clog while the others did. This observation suggests that the silk used in the Recorder for a Great Lakes plankton survey should be as coarse as practical, to minimize clogging. However, usually the #4 had almost the same meter reading as the other two silks so its use in preference to the others will only make an appreciable difference occasionally.

The tows described above were also used to compare the plankton-catching abilities of the three mesh sizes. A representative fraction of the zooplankton caught on each of the silks was identified to allowed comparisons.

Identification of the zooplankton on the silks was carried out in a manner modified from that used in the marine survey explained by Colebrook (1960). After a band of silk had been towed, it was separated into three blocks by cutting it where it had been glued together. A staggered microscope traverse was taken across both the filtering and the covering silks of each block, and all the crustaceans that were observed using the low power objective (43.75X) were picked off. These animals were identified following the keys in Edmondson (1959). In some cases such large numbers of animals were picked off that it was necessary to limit the identifications to only a certain known fraction. The fraction for counting was obtained by splitting the sample once or twice using a Folsom Plankton Splitter.

Results of these identifications are presented in Table 2. Identifications were made on the tows for every date except October 5, 1965. This sample was omitted to decrease the time and effort expended in analysis. Samples from September and November were analyzed to give a picture of fall conditions.

Comparisons of the plankton caught on the different silks on the same

TABLE 2. Comparisons of the abundance (individuals/m^3) of crustaceans caught in a Continuous Plankton Recorder using #4 (62 meshes/inch), #7 (82 meshes/inch), or #10 (109 meshes/inch) bolting cloth on four dates in Lake Michigan.

		#4	#7	#10
13-IX-65	Aliquot	1	1	1/4
Cladocera				
Daphnia retrocurva		131	314	88
D. longiremis		0	4	0
D. galeata mendotae		0	44	0
Bosmina longirostris		11	80	73
B. coregoni		4	69	29
Leptodora kindti		0	18	0
Diaphanosoma brachyurum		0	4	0
Holopedium gibberum		0	4	0
Unidentifiable *Daphnia*		0	77	0
Unidentifiable *Bosmina*		0	47	0
Unidentifiable cladocerans		4	29	0
Total Cladocera		150	690	190
Cyclopoida				
Cyclops bicuspidatus adults		11	208	58
Tropocyclops prasinus adults		4	11	117
Immature copepodids		26	756	628
Unidentifiable cyclopoids		0	47	44
Total Cyclopoida		41	1022	847
Calanoida				
Diaptomus oregonensis adult males		26	58	0
adult females		11	4	0
D. ashlandi adult males		7	22	0
adult females		7	7	15
D. minutus adult males		0	7	0
adult females		7	11	0
Immature diaptomid copepodids		219	1394	1504
Total *Diaptomus*		277	1503	1519
Eurytemora affinis		0	4	0
Epischura lacustris		84	4	15
Unidentifiable calanoids		4	22	15
Total Calanoida		365	1533	1549

TABLE 2 continued

	#4	#7	#10
Miscellaneous			
Unidentifiable copepods	0	66	0
Nauplii	7	18	44
Cladocera embyros	0	11	0
Total Miscellaneous	7	95	44
Total all crustaceans	563	3340	2630

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10-XI-65 Aliquot	1/2	1/4	1/2
Cladocera			
Daphnia retrocurva	15	29	7
D. galeata mendotae	0	15	0
Bosmina longirostris	7	73	51
B. coregoni	66	234	29
Leptodora kindti	0	0	7
Unidentifiable *Daphnia*	7	0	0
Unidentifiable *Bosmina*	73	146	22
Unidentifiable Cladocera	15	15	0
Total Cladocera	183	512	116
Cyclopoida			
Cyclops bicuspidatus adults	15	29	22
Tropocyclops prasinus adults	0	29	29
Immature copepodids	387	788	1190
Unidentifiable cyclopoids	0	0	15
Total Cyclopoida	402	846	1256
Calanoida			
Diaptomus oregonensis adult males	22	73	7
adult females	44	15	15
D. ashlandi adult males	0	0	0
adult females	0	15	0
D. minutus adult males	73	102	44
adult females	37	15	22
D. sicilis adult males	7	0	0
adult females	7	0	0
Immature diaptomid copepodids	307	292	299

TABLE 2 continued

	#4	#7	#10
Total *Diaptomus*	497	512	387
Epischura lacustris	0	0	7
Unidentifiable calanoids	29	15	0
Total Calanoida	526	527	394
Miscellaneous			
Unidentifiable copepods	15	0	15
Nauplii	0	0	15
Cladocera embyros	0	15	0
Total Miscellaneous	15	15	30
Total all crustaceans	1126	1900	1796
22-IV-66 Aliquot	1/2	1/2	1
Cladocera			
Total Cladocera	0	0	0
Cyclopoida			
Cyclops bicuspidatus adults	467	365	69
Immature copepodids	73	58	44
Unidentifiable cyclopoids	0	0	7
Total Cyclopoida	540	423	120
Calanoida			
Diaptomus oregonensis adult males	22	7	0
adult females	7	29	0
D. ashlandi adult males	7	29	0
adult females	44	44	7
D. minutus adult males	15	73	7
adult females	37	95	18
D. sicilis adult males	0	7	0
adult females	0	0	0
Immature diaptomid copepodids	0	0	4

TABLE 2 continued

		#4	#7	#10
Total *Diaptomus*		132	284	36
Limnocalanus macrurus		7	0	0
Unidentifiable calanoids		15	22	0
Total Calanoida		154	306	36
Miscellaneous				
Nauplii		0	15	7
Total Miscellaneous		0	15	7
Total all Crustaceans		694	744	163
- - - - - - - - - - - - - - - - - - - -				
30-VI-66	Aliquot	1/4	1/4	1
Cladocera				
Daphnia longiremis		15	15	0
Bosmina longirostris		15	15	37
B. coregoni		15	73	7
Unidentifiable *Bosmina*		29	117	18
Total Cladocera		74	220	62
Cyclopoida				
Cyclops bicuspidatus adults		438	569	55
Immature copepodids		642	2132	245
Unidentifiable cyclopoids		0	0	7
Total Cyclopoida		1080	2701	307
Calanoida				
Diaptomus oregonensis adult males		73	15	7
adult females		15	29	0
D. ashlandi adult males		248	131	0
adult females		117	0	0
D. minutus adult males		73	0	0
adult females		15	44	4
Immature diaptomid copepodids		117	204	33

TABLE 2 continued

	#4	#7	#10
Total *Diaptomus*	658	423	44
Epischura lacustris	15	0	0
Unidentifiable calanoids	15	0	0
Total Calanoida	688	423	44
Miscellaneous			
Nauplii	15	15	18
Total Miscellaneous	15	15	18
Total all Crustaceans	1857	3359	431

date are very rough. The three silks compared from each series of towings were towed at slightly different times and only over approximately the same path. As zooplankton distributions are notoriously patchy both spatially and temporally, differences in the quality and quantity of zooplankton on the different silks may as well be attributed to differences in the plankton assemblages sampled as to differences in the catching abilities of the different silks. However, four sets of comparisons were analyzed. It is assumed that most differences due to factors other than the catching abilities of the silks will tend to balance out over the four comparisons and that any very obvious and extensive differences are probably due to the different plankton-catching abilities of the different silks.

A quick examination of Table 2 shows one outstanding fact. The #7 bolting cloth catches more than either of the other silks in the great majority of cases. For each of the four series of tows, the #7 silk caught the

largest total number of zooplankters. Even considering the different organisms separately, the #7 silk almost always had the largest catch. Occasionally, the #4 silk caught more of one of the larger organisms, such as one of the species of adult calanoids, or the #10 silk caught more of one of the smaller organisms, such as the immature cyclopoids or the *Tropocyclops prasinus* adults, but generally the #7 silk caught the most.

It is not surprising that the #7 silk usually catches more than the #4 silk, for it has finer meshes and so will let fewer individuals through. In the case of organisms that are too large to go through even the #4 silk, this reasoning no longer holds. Thus, as was observed, the superior catching ability of the #7 silk would not hold for the largest animals.

Much more surprising is the observation that the #7 silk usually catches larger numbers of the different zooplankters than the #10 silk. Only for the very smallest organisms, which almost entirely escape the #7 silk, is this untrue. At this time it is impossible to explain why the finer mesh #10 silk catches so few animals. It could be that this silk is so fine that it does not filter the water as easily as the other silks. This difficulty in filtering might tend to push water ahead of the Recorder and so warn the animals of the instrument's approach. However, the flow meter readings do not indicate any appreciable difference in water filtered between the #10 and #7 silks.

The results in this section leave little doubt as to which of these mesh sizes is preferable for use in a Recorder survey on the Great Lakes plankton. While the #4 silk is somewhat better with regard to avoiding clogging, the #7 silk is by far the best for catching the crustaceans. Only for the very largest animals would the #4 silk be of much use. The #10 silk is unsatisfactory both with regard to plankton-catching ability and filtering efficiency.

Determination of Silk Winding Speed

The rate at which the bands of silk are wound through the Recorder in relation to the amount of towing can be varied by altering the pitch of the blades of the propeller that drives the winding mechanism. The faster the winding rate, the lower the chance of clogging; for the faster the silks are wound, the less time any part of the filtering silk is exposed in the water tunnel. Yet, the storage spool in the Recorder can only accommodate so much silk, so if the silks are wound on at a fast rate they will soon fill the storage spool. When the spool is full, the Recorder must be brought aboard and reloaded with fresh silks after removing the towed silks.

In the marine survey the blades of the propeller are set so that approximately 4 inches of silk is wound on the storage spool for every 10 miles of towing. This rate is a compromise in that it allows towing for up to 600 miles without changing silks and yet keeps the amount of plankton on the silks low enough so that clogging is seldom a serious problem (Hardy 1939). There are usually appreciable numbers of crustaceans on a block of silk from the marine survey, but not so many as to completely cover the block and make analysis difficult.

It was decided to attempt to set the winding rate of the Recorder in the Great Lakes so as to obtain quantities of plankton on the silks roughly comparable to the quantities obtained in the marine survey. Although other zooplankters commonly occur in the marine survey, crustaceans and specifically copepods make up the bulk of the animals found on the typical silk, as in the Great Lakes. The total number of copepods of all species observed while traversing each sample block is routinely counted in the marine survey. Colebrook and Robinson (1965) report on these counts. Their data indicate that 100 to 500 copepods are usually seen on a transect. That is approximately 1,300 to 6,500 copepods per m^3.

Table 2 shows that the total numbers of crustaceans found in Lake Michigan on test tows of the Recorder with #7 silk are within the range found in the marine survey. This result was obtained with the winding rate set, as in the marine survey, at approximately 4 inches for each 10 miles of towing. The silks obtained in these tests looked similar to the usual marine silks in amount of the silk covered by plankton and were comparable in ease of counting to the marine silks. Thus, it seems that the quantity of plankton in Lake Michigan caught by the Recorder is roughly the same as that usually obtained in the North Atlantic, and so the winding rate should be set the same.

A preliminary study was conducted that can be used to determine whether the winding rate that was decided upon for Lake Michigan would also be useful in other Great Lakes. Test runs with the Recorder were made in Lakes Michigan, Huron, and Erie. These tests were conducted through the cooperation of the U. S. Bureau of Commercial Fisheries, who made available their research vessel CISCO. A Recorder was towed during August 1963 at a depth of 10 m for 100 miles in Lake Michigan, 81 miles in Lake Huron, and 69 miles in Lake Erie. These studies were conducted before it had been determined that #7 (82 meshes/inch) silk was preferable for Great Lakes work, and so 60 meshes per inch silk was used. The samples were analyzed by the methods used in the marine Recorder survey (Colebrook 1960). These analyses were carried out at the Edinburgh Oceanographic Laboratory during the author's stay there.

One 4-inch block of silk from each lake was analyzed, and the results are given in Table 3. The winding rates in Lakes Michigan and Huron were approximately 4 inches per 10 miles of towing, as in the marine survey. These blocks had somewhat less plankton than the typical marine block,

TABLE 3. Comparison of the numbers of several crustaceans (individuals/m^3) caught in Lakes Michigan, Huron, and Erie in August 1963 using the Continuous Plankton Recorder.

Animal	Lake		
	Erie	Huron	Michigan
Cyclopoids	3450	285	64
Diaptomus	4250	326	51
Daphnia	4250	150	230
Bosmina	1000	109	345
Ceriodaphnia	700	---	---
Diaphanosoma	1750	---	---
Leptodora	---	13	---
Holopedium	---	408	38
Polyphemus	---	13	13
Total crustaceans	15400	1304	741

however, the block from Lake Michigan also had less total animals than found on the #7 silks discussed previously. The coarse silk used in these preliminary runs probably allowed the escape of a large number of individuals. As the quantities of crustaceans caught in Lake Huron and Michigan were roughly similar, it seems likely that a winding rate of 4 inches per 10 miles would be appropriate for both lakes.

As can be seen from Table 3, the block from Lake Erie had many more animals than were found from Lakes Michigan and Huron. Because it was already known that Lake Erie had high concentrations of zooplankters, the winding rate had been set to be much faster in this lake than in the other two lakes. Even so, with the rate at 4 inches per 1.68 miles of towing,

the silks were thickly covered with plankton, and it seems likely that filtering efficiency was decreased. These blocks were covered at least as much as the most heavily covered blocks from the marine survey. If #7 silks had been used, even more animals would have been caught.

These results indicate that a much faster winding rate should be used for Recorder tows in Lake Erie than in the other lakes. A rate of 4 inches per 1 mile of towing or even faster seems called for when using #7 silk. However, as the Recorder is presently constructed, the rate used in Lake Erie during these preliminary tows is about the fastest possible. It may be that a change in the gear reduction ratio between the propeller, exposed to the water flow, and the storage spool would be necessary if the Recorder were to be used for an extensive survey in Lake Erie.

Determination of Towing Depth

The samples for the marine Recorder survey were all taken from a depth of 10 m, the depth chosen as most likely to give consistent results (Hardy 1939). Studies conducted by the Edinburgh Laboratory indicated this depth as having the minimal seasonal and diurnal variations in vertical distribution of plankton in the North Sea. The depth of towing can be controlled, within limits, by controlling the amount of wire between the ship and the Recorder. The towing depth for a Great Lakes plankton survey could be varied from 10 m if there were reasons indicating some other depth would be preferable.

To make an intelligent decision as to what towing depth would give the most consistent results in the Great Lakes, it is necessary to have some idea of the variations in vertical distribution of the Great Lakes plankters. However, a study to give a picture of variations in vertical distribution was beyond the scope of the present research. Fortunately, Wells (1960)

presents data on the abundance of the planktonic crustacean species of Lake Michigan at different depths on several different dates. His data have been analyzed to determine what depth would be optimum for towing the Recorder.

On ten dates in 1954 and 1955, Wells took a series of horizontal plankton tows at different depths with a calibrated Clarke-Bumpus plankton sampler. These samples were analyzed so that his paper includes a table for each common species showing its abundance at a series of depths for each date. For the purposes of the present study, it was impractical to study the vertical distribution of each individual species. Instead, the data have been combined to give the abundance of the total crustacean plankton at each depth on each sampling date. These totals are presented in Table 4.

The results in this table show consistent differences among depths in abundance. Generally, the deeper samples had fewer individuals than the shallower ones. There seem to be consistent differences among depths in the amount of variation in abundance during a sampling period. The surface station tends to have more variability in abundance during a sampling period than the other depths.

To give a more precise picture of these differences, the data for each sampling period have been averaged and the coefficient of variability within the sampling period calculated for each depth (Table 5). It will be noted from the table that the 10-m depth has relatively large numbers of animals and relatively low coefficients of variability. Sampling at this depth should provide samples representative of the conditions in the upper waters with the minimum distortion of individual results due to variability in vertical distribution. Thus, there seems to be no reason to change the Recorder towing depth from 10 m for a survey in the Great Lakes.

TABLE 4. Abundance (individuals/m^3) of the total crustacean plankton at different depths in Lake Michigan on a series of sampling dates. These data were obtained by summing the individual species values for abundance presented in Wells (1960).

Date	Depth (m)					
	Surface	5	10	20	30	40
June 6-7, 1954						
2:00 p.m.	0	---	3,820	---	---	---
4:00 p.m.	20	---	2,338	---	---	---
6:00 p.m.	163	---	2,561	---	---	---
8:40 p.m.	2,743	---	1,967	---	---	---
10:00 p.m.	7,142	---	2,337	---	---	---
12:00 p.m.	4,283	---	1,751	---	---	---
1:00 a.m.	2,311	---	---	---	---	---
June 27, 28						
10:00 p.m.	---	---	5,537	---	---	---
12:00 p.m.	9,274	---	3,206	1,971	586	---
2:00 a.m.	8,799	---	---	2,347	---	---
4:00 a.m.	6,745	---	6,546	2,542	1,837	---
July 16, 17						
7:00 p.m.	3,999	---	5,218	5,973	2,468	992
9:00 p.m.	16,038	---	5,164	4,261	2,185	1,220
11:00 p.m.	22,850	---	6,872	4,629	1,782	893
1:00 a.m.	12,847	---	7,568	4,998	1,518	1,053
3:00 a.m.	13,430	---	9,289	4,653	1,922	863
4:30 a.m.	5,506	---	11,151	3,520	1,409	918
August 7						
5:30 p.m.	365	---	12,857	5,423	1,599	1,693
7:45 p.m.	7,702	---	14,356	3,904	1,711	949
9:30 p.m.	13,593	---	12,431	4,120	1,787	1,519
11:00 p.m.	16,434	---	7,785	3,175	1,358	1,591
August 27						
5:45 p.m.	76	---	2,680	4,789	2,329	---
7:30 p.m.	475	---	3,232	4,050	---	831
9:00 p.m.	8,654	---	2,129	3,934	1,796	1,476
11:00 p.m.	5,531	---	2,855	6,176	---	853
October 7						
5:15 p.m.	1,778	---	6,682	3,187	644	766
7:00 p.m.	7,502	---	8,974	2,026	734	---
9:15 p.m.	6,001	---	6,719	2,158	1,116	532
November 18						
4:30 p.m.	1,896	---	7,019	1,771	944	640
6:00 p.m.	11,421	---	9,348	1,132	1,595	---
8:00 p.m.	8,814	---	---	---	951	750
10:00 p.m.	11,216	---	3,600	2,216	911	---

TABLE 4 continued

Date	Depth (m)					
	Surface	5	10	20	30	40
June 30, 1955						
6:00 p.m.	917	2,224	2,383	3,918	4,241	893
8:30 p.m.	2,809	2,857	2,181	2,809	1,595	1,551
11:30 p.m.	3,329	5,473	2,768	2,600	1,147	510
July 24						
4:15 p.m.	577	4,873	10,050	9,176	1,543	364
6:15 p.m.	1,605	3,133	5,964	3,427	514	244
8:15 p.m.	3,295	4,437	6,124	4,103	---	404
10:45 p.m.	7,882	7,037	4,877	2,873	387	150
October 2						
2:00 p.m.	210	4,393	9,330	---	---	---
4:20 p.m.	583	8,009	7,171	6,489	1,124	6,045
6:30 p.m.	3,737	9,249	5,991	3,008	1,516	2,016
8:20 p.m.	4,998	10,656	6,330	2,043	1,102	494
10:30 p.m.	5,738	3,165	---	---	1,079	193

TABLE 5. The mean abundance ($\bar{x}$), variance (s^2), standard deviation (s), and coefficient of variability (CV) of total crustacean plankton at different depths at a series of dates in Lake Michigan. These values are based on data of Wells (1960).

Date	Depth (m)					
	Surface	5	10	20	30	40
1954						
June 6, 7						
$\bar{x}$	2,380	---	2,462	---	---	---
s^2	7,097,279	---	527,102	---	---	---
s	2,664	---	726	---	---	---
$CV = \frac{100s}{\bar{x}}$	111.93	---	29.49	---	---	---
June 27, 28						
$\bar{x}$	8,273	---	5,096	2,287	1,212	---
s^2	1,806,731	---	2,934,541	84,241	782,500	---
s	1,344	---	1,713	290	885	---
CV	16.25	---	33.61	12.68	73.02	---

TABLE 5 continued

Date	Depth (m)					
	Surface	5	10	20	30	40
July 16, 17						
$\bar{x}$	12,445	---	7,544	4,672	1,881	990
s^2	48,358,028	---	5,516,462	659,422	160,604	17,519
s	6,954	---	2,349	812	401	132
CV	55.88	---	31.14	17.38	21.32	13.33
August 7						
$\bar{x}$	9,524	---	11,857	4,156	1,614	1,438
s^2	50,503,942	---	8,051,887	877,483	35,033	111,372
s	7,107	---	2,838	937	187	334
CV	74.62	---	23.94	22.55	11.59	23.23
August 27						
$\bar{x}$	3,684	---	2,724	4,737	2,063	1,053
s^2	17,142,551	---	210,395	1,063,401	142,044	134,107
s	4,140	---	459	1,031	377	366
CV	112.38	---	16.85	21.76	18.27	34.76
October 7						
$\bar{x}$	5,094	---	7,458	2,457	831	649
s^2	8,808,485	---	1,723,277	404,031	62,802	27,377
s	2,968	---	1,313	636	251	165
CV	58.26	---	17.61	25.89	30.20	25.42
November 18						
$\bar{x}$	8,337	---	6,656	1,706	1,100	695
s^2	19,837,902	---	8,358,885	296,901	109,094	6,050
s	4,454	---	2,891	545	330	78
CV	53.42	---	43.43	31.95	30.00	11.22
1955						
June 30						
$\bar{x}$	2,352	3,518	2,444	3,109	2,328	985
s^2	1,611,303	2,966,691	88,933	501,781	2,795,810	277,223
s	1,269	1,722	298	708	1,672	527
CV	53.95	48.95	12.19	22.77	71.82	53.50
July 24						
$\bar{x}$	3,340	4,870	6,754	4,895	815	291
s^2	10,425,394	2,633,519	5,135,915	8,399,244	401,885	13,396
s	3,229	1,623	2,266	2,898	634	116
CV	96.68	33.33	33.55	59.20	77.79	39.86

TABLE 5 continued

Date	Depth (m)					
	Surface	5	10	20	30	40
October 2						
$\bar{x}$	3,053	7,094	7,206	3,847	1,205	2,187
s^2	6,410,914	10,225,384	2,252,067	5,469,251	43,256	7,251,897
s	2,532	3,198	1,501	2,339	208	2,693
CV	82.93	45.08	20.83	60.80	17.26	123.14

A COMPARISON OF SOME BIOLOGICAL PROPERTIES SAMPLED ON THE CRUISE OF A MERCHANTMAN FROM DETROIT, MICHIGAN TO BILBOA, SPAIN

As an inexpensive means of collecting oceanographic and limnological data, it has been suggested that commercial vessel during their regular passage might be used as collecting platforms (Research Ships of Opportunity concept). The feasibility of this concept has been tested both in the Atlantic and the Pacific, and the results have shown that it holds great promise. During the summer of 1966 the feasibility studies were expanded to include a cruise that was partially in fresh and partially in salt water. The Principal Investigator participated in this cruise and has published the experiences obtained in planning, preparing for, and carrying out the project elsewhere (Robertson 1967).

The waters of a river system change gradually as they flow to the sea and then change abruptly as they meet the sea and flow out the estuary. For practical reasons, very few studies have been conducted to study these changes in a large river system, starting a great distance inland and continuing out into the open ocean. The Research Ships of Opportunity project mentioned above provided an excellent opportunity to conduct such studies. The scientific objective of the project was to conduct a comparison of certain environmental properties along the line of cruise.

The properties selected for study were the amount of particulate organic matter, the amount of dissolved organic matter, the composition of the zooplankton community, the temperature, and the conductivity. These were selected because it was felt they would facilitate meaningful comparisons among the biological communities in the different environments and because they lent themselves to relatively simple measurement on the merchant vessel.

The results of the measurements, with a brief comparison of the different environments, are presented here. Part of this information has been used previously in a comparison of the five St. Lawrence Great Lakes (Robertson and Powers 1967).

Temperature

Sampling procedures and stations used for this study have been explained in Robertson (1967). Briefly, however, water samples from a depth of 24 ft were drawn from the main injection line of the ship once every two, three, or four hours while underway, depending upon the rate at which the environment was changing. The temperature of each water sample was measured as soon as it was taken. These values have been plotted versus sample number in Figure 1.

Temperatures during the freshwater part of the cruise were generally relatively high, with the highest temperatures occurring in the shallow, western end of Lake Erie. Lake Ontario had somewhat lower temperatures, with the sample from the middle of the lake being by far the coolest. At the entrance to the St. Lawrence from Lake Ontario, the temperature was high, while the temperatures down the rest of the river were somewhat lower and relatively constant. The largest change in temperature during the cruise was that encountered in going from fresh to salt water at the mouth of the St. Lawrence. Cold water comes into the Gulf of St. Lawrence through the Strait of Belle Isle between Newfoundland and the mainland and sometimes also from around Newfoundland. This water keeps especially the northern part of the Gulf of St. Lawrence and the St. Lawrence estuary cool. As we went out from the mouth of the St. Lawrence, the temperature rose until we got to the warm waters coming up from the south in the Gulf Stream. The temperature then stayed relatively constant for the rest of our cruise.

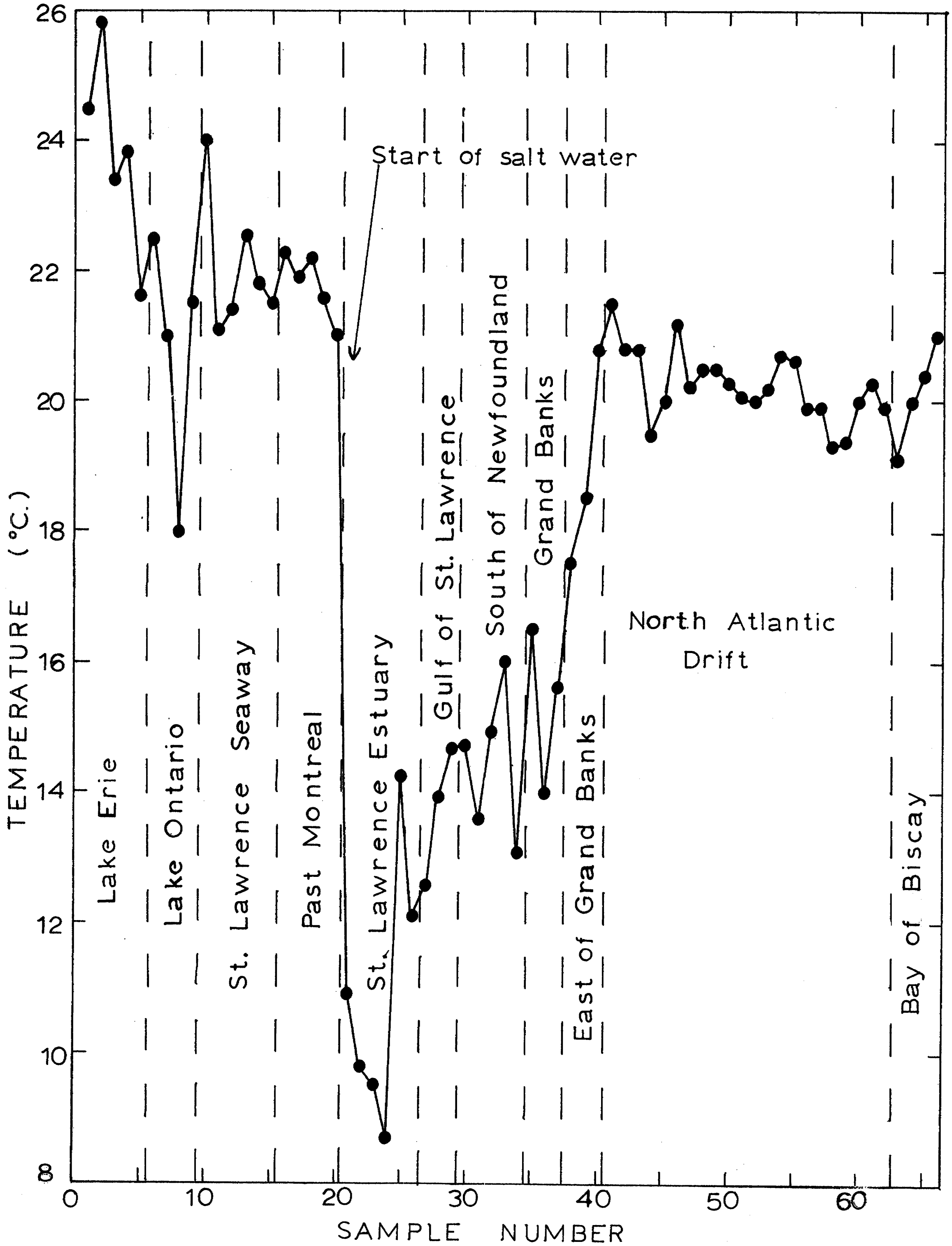

FIG. 1. Water temperature plotted by sample number for a cruise from Detroit, Michigan to Bilboa, Spain.

However, there was a noticeable, though slight, tendency for decreasing temperatures as we proceeded eastward in the North Atlantic Drift. This cooling tendency was reversed in the Bay of Biscay as we approached the Spanish coast, by a distinct rise in temperature.

Conductivity

The specific conductance compensated to a temperature of 25°C was measured on each sample, using a conductivity bridge. There is a great difference between the values for fresh and those for salt water, and so the results from these environments have been plotted separately versus sample number (Figs. 2, 3).

The conductivity values start out relatively low, with the two values from western Lake Erie being around 2.75×10^{-4}. Then the values jump up to between 3.30×10^{-4} and 3.45×10^{-4} for most of the rest of the freshwater part of the cruise. Only the last couple of measurements at the mouth of the river again fall to lower values. A suggestion as to the cause of these lower values at the start and end of the freshwater part of the cruise will be discussed in the following subsection.

Excluding these lower values at the mouth, it will be noted that the tendency was for a slight increase in conductivity as we progressed downstream. Intuitively, it would seem reasonable to expect the quantity of dissolved salts to increase as the waters flow past such metropolitan centers as Cleveland, Buffalo, Toronto, and Montreal. Why a more noticeable increase in conductivity was not noted is not evident at this time.

The saltwater part of the cruise shows, in general, increasing conductivity (expressed as salinity) as we proceeded across the Atlantic. The lowest value of about 19 °/00 was found in the first sample in salt water, where the influence of the river water was still strongly felt. After this,

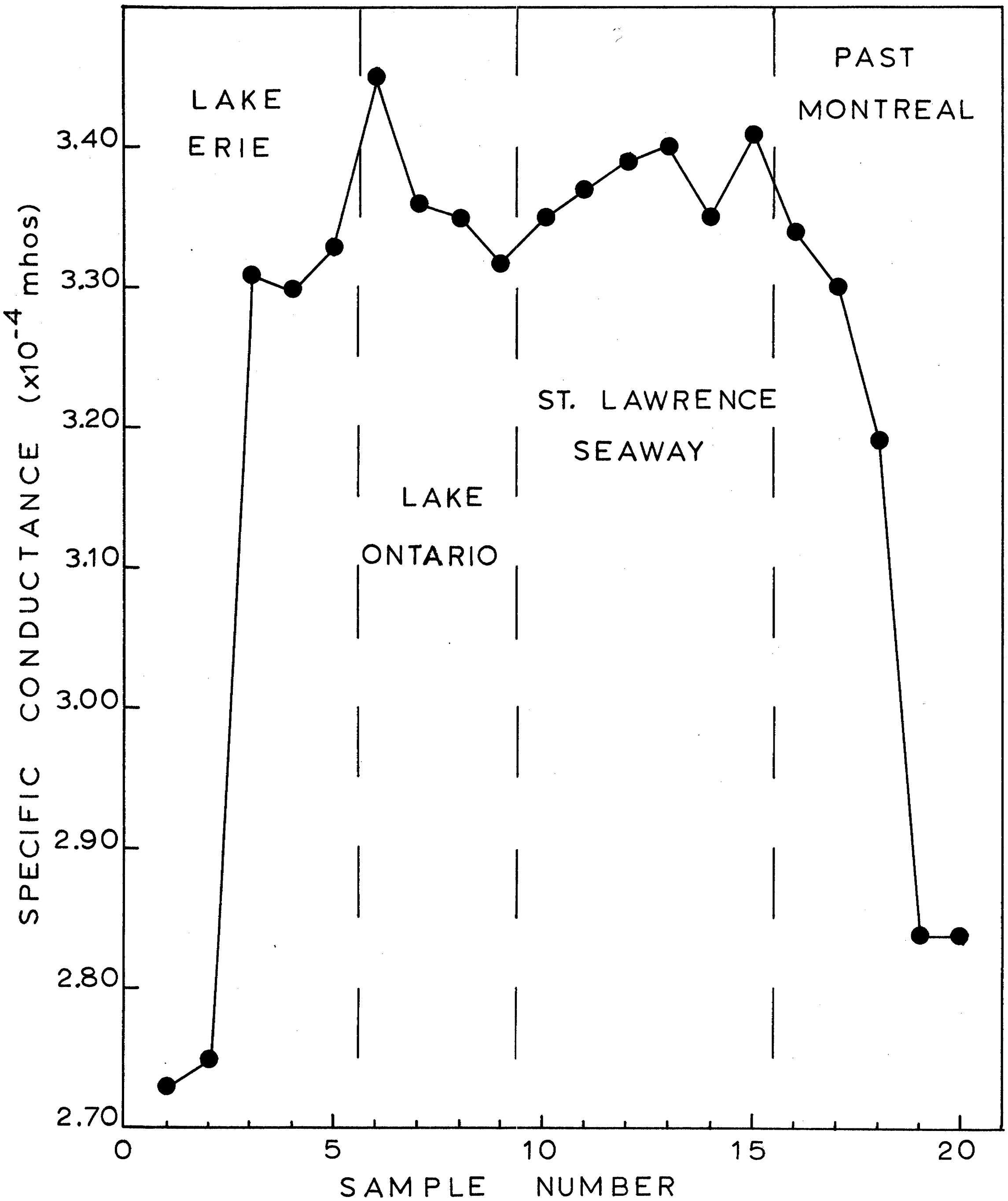

FIG. 2. Specific conductance plotted by sample number for the freshwater part of a cruise from Detroit, Michigan to Bilboa, Spain.

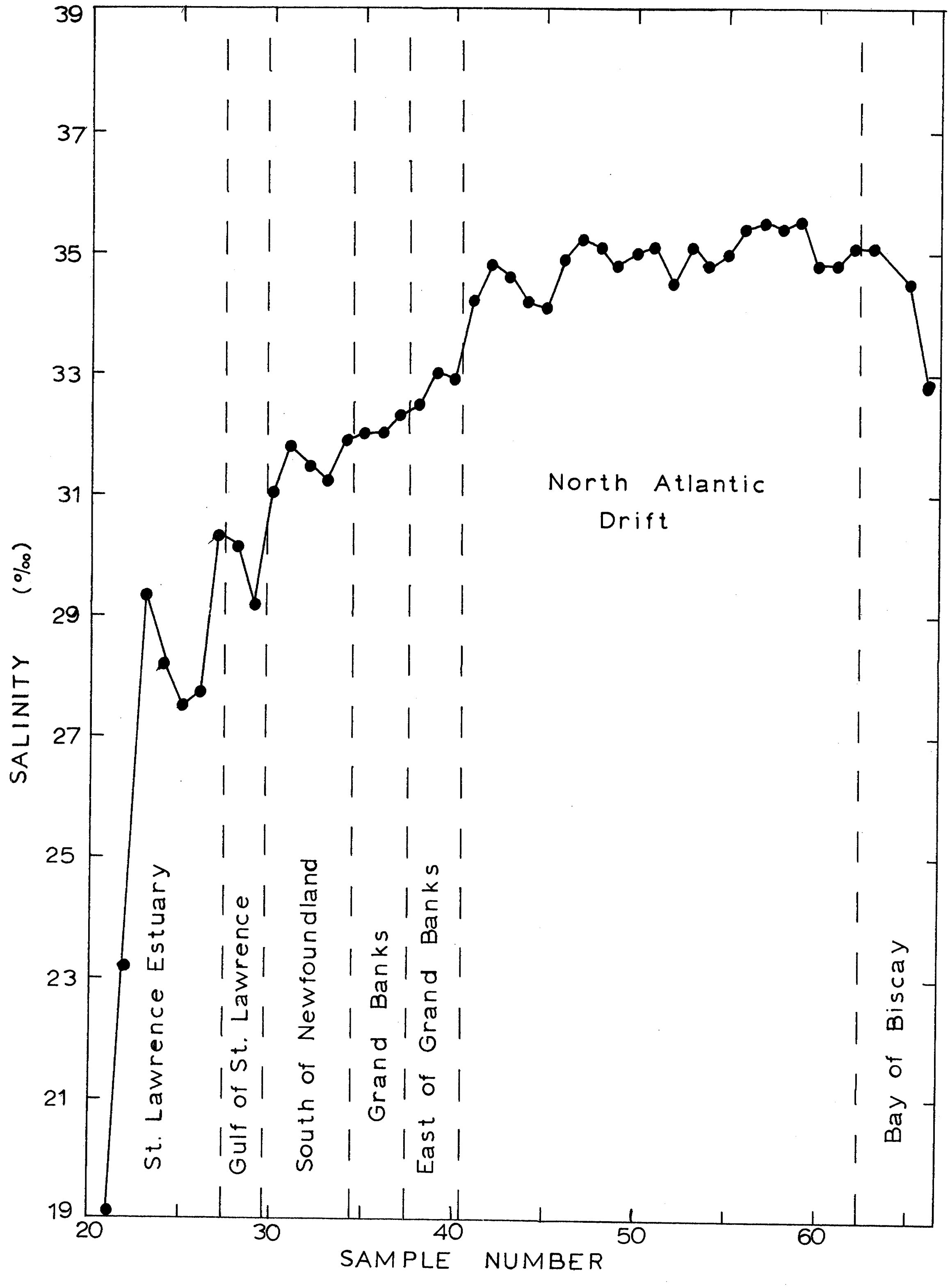

FIG. 3. Salinity plotted by sample number for the saltwater part of a cruise from Detroit, Michigan to Bilboa, Spain.

the values rose and fell to some extent, but, in general, they increased until we got into the North Atlantic Drift. This rising trend is due to the decreasing influence of land drainage and of Labrador Current water and to the increasing influence of Gulf Stream water from the south. This water has a higher salinity than the Labrador Current water, which comes down from the north, so the salinity increases as the Gulf Stream influence becomes more strongly felt. For the rest of the cruise, the salinity stayed at relatively high values around 35 °/00, except just off the Spanish coast where it fell somewhat, again probably due to the influence of land drainage. It is possible to separate the major marine environments encountered during the cruise by plotting salinity versus temperature (Fig. 4).

Particulate Organic Matter and Dissolved Organic Matter

The values for particulate and dissolved organic matter have been plotted together in Figure 5 because the two properties show such similar trends. Only the values for the freshwater part of the cruise are treated here. For measuring particulate organic matter in fresh water we used the method of Robertson and Powers (1965). This method entails filtering the water through a 0.8μ, pre-weighed membrane filter, reweighing the filter after drying, and considering the difference between the two weights as the weight of particulate matter. The filter plus particulate matter was then ashed and the weight of ash subtracted from the particulate matter value to give an estimate of particulate organic matter. (The filter is essentially ash-free.)

It had been hoped to follow this same procedure for measuring the particulate organic matter in the salt water, and, in fact, such measurements were made. However, these measurements have not been included here because it was found that in salt water the filters gained weight that could not be

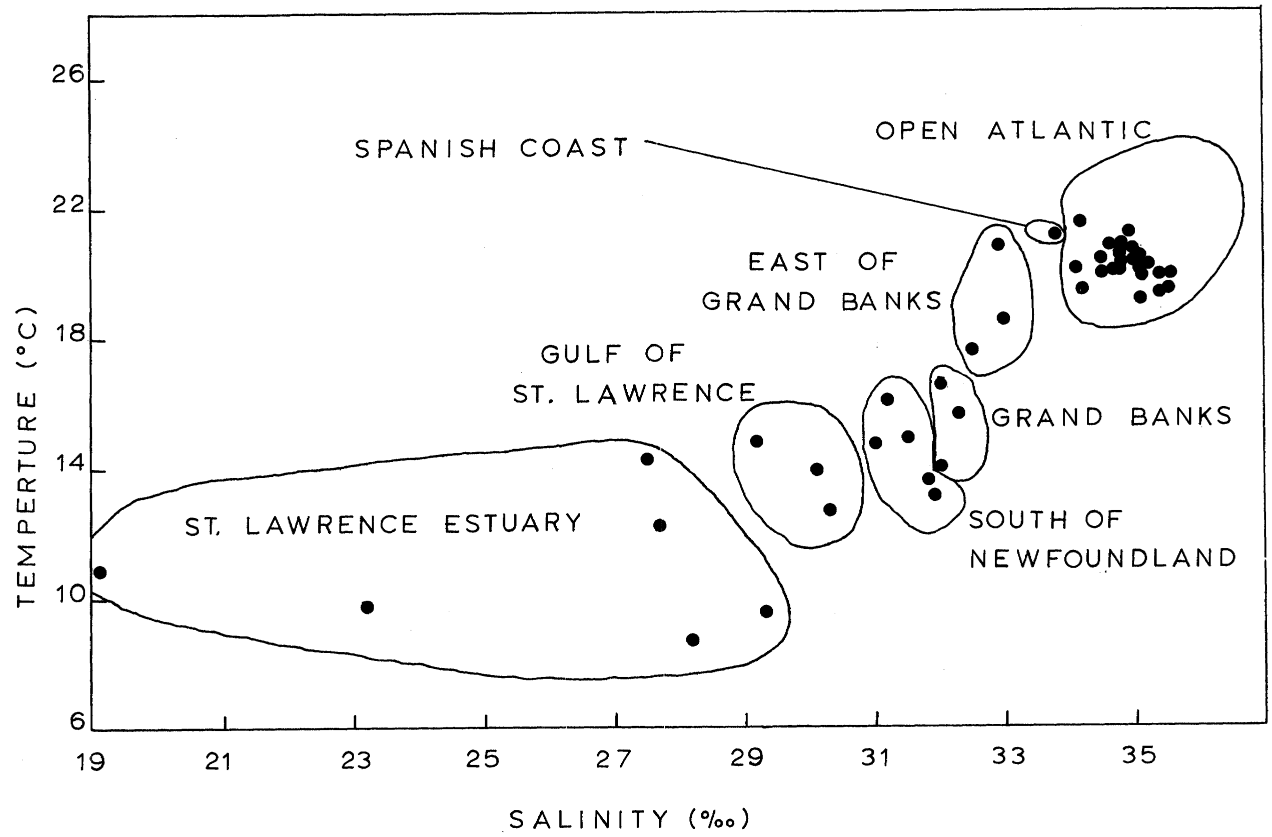

FIG. 4. A temperature-salinity diagram for the saltwater part of a cruise from Detroit, Michigan to Bilboa, Spain.

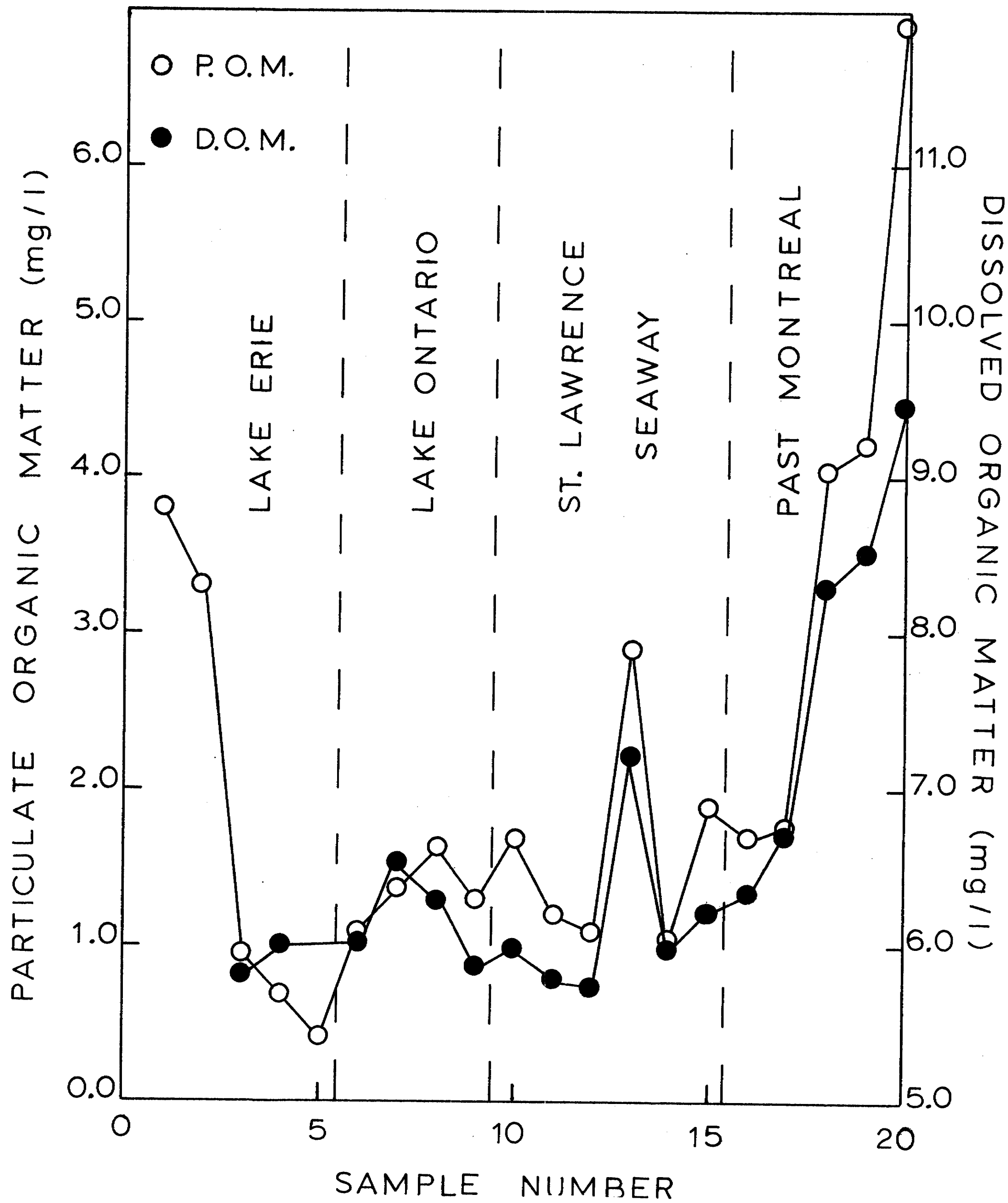

FIG. 5. The amounts of particulate organic matter and of dissolved organic matter plotted by sample number for the freshwater part of a cruise from Detroit, Michigan to Bilboa, Spain.

attributed to particulate matter. This weight increase could not be eliminated by repeated washings with distilled water. The gain in weight on exposing the filters to salt water occurred even after the water had been filtered as many as sixteen times, thus eliminating any possibility that the weight gain could be caused by retention of particulate matter. It is postulated that some of the salt ions were adsorbed so strongly by the filters that even repeated washing with distilled water would not cause their resolution.

Dissolved organic matter was measured by a dichromate oxidation method following, with some modification, Maciolek (1962). The factor given by Maciolek to enable the results to be expressed in terms of organic matter has been used. Both particulate and dissolved organic matter were measured in triplicate each time samples were taken. Samples for measuring dissolved organic matter were not taken at the start of the cruise because the samples had to be frozen for return to the laboratory, and the freezer could not be connected to a source of electric power for the first few hours.

Results for the two properties show very similar trends. Values for particulate organic matter were high in western Lake Erie, where dissolved organic matter was not measured. The high values were probably due to the wastes released into the western end of the lake by Detroit. These wastes contain large quantities of settleable solids as well as high concentrations of plant nutrients. The solids would be measured directly while the nutrients would stimulate phytoplankton growth which would cause increased quantities of particulate organic matter.

Both particulate and dissolved organic matter were relatively low in the rest of Lake Erie and only somewhat higher in Lake Ontario. They were about the same in the St. Lawrence as in Lake Ontario except in sample 13.

This sample was taken just downstream from what appeared to be a large paper mill on the shore. The wastes from this mill could be the cause of the high values for both properties at this one point in the river.

At the mouth of the river the values for both properties go up to very high levels, possibly due to the waters of the river slowing down here as the estuary begins. These waters have been enriched as they flow past Montreal and other cities along the river but have been flowing too fast and have been too turbulent for large populations of phytoplankton to develop. Here, at the mouth, the river widens, and so it flows slowly enough for the algae to take advantage of the nutrients. Also, with decreased turbulence, the phytoplankters have a better chance of staying in the lighted, upper water layers. A further contributing factor may be the layer of salt water that flows well up the estuary. This underlying layer of high density water causes the development of a stable two-layered system that further prevents the algae from being carried into the deeper waters and out of the euphotic zone.

During the freshwater part of the cruise there seemed to be an inverse correlation between amount of particulate organic matter and specific conductance (Fig. 6). If it is assumed that the areas of high particulate organic matter are areas of phytoplankton blooms, then this increased organic production may reduce the specific conductance by tying up some of the ions in phytoplankton biomass.

Composition of the Zooplankton Communities

The zooplankton communities in Lakes Erie and Ontario and in the St. Lawrence Estuary and the Gulf of St. Lawrence were sampled using the Continuous Plankton Recorder. Maps showing the paths of towing are included in Robertson (1967). The Recorder and its use are described in the preceding

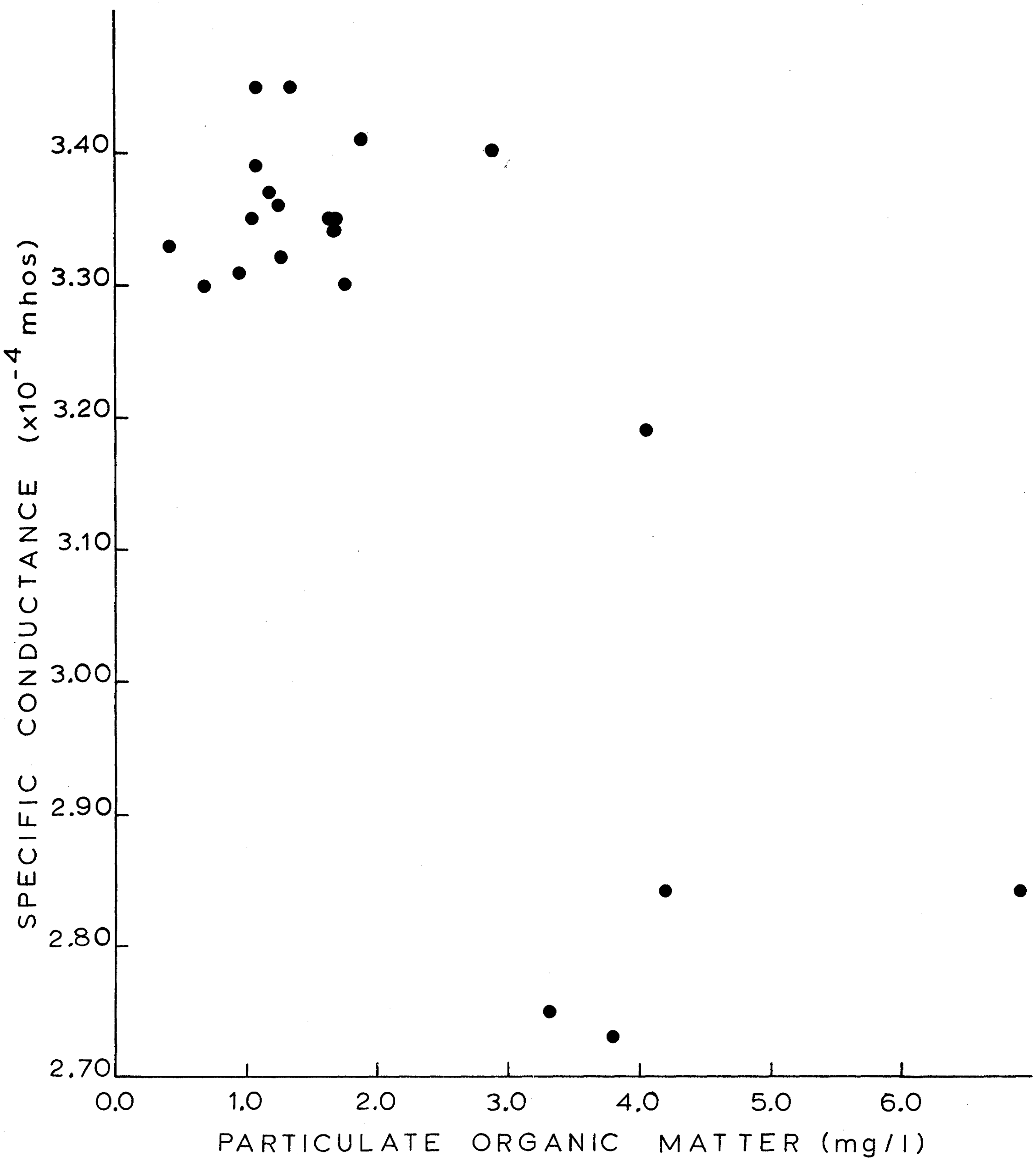

FIG. 6. The relation between amount of particulate organic matter and specific conductance for the freshwater part of a cruise from Detroit, Michigan to Bilboa, Spain.

section of this report. For our tows the Recorder was fitted with 60 meshes per inch silk, was towed at 10 m depth, and was set so that approximately 4 inches of silk was wound through for every 10 miles of towing.

The freshwater samples from Lakes Ontario and Erie were analyzed in our laboratory. The towed silks were cut into blocks, each representing 10 miles of towing, and the blocks numbered consecutively, with block #1 containing the plankton from the first 10 miles. A staggered microscope traverse was run across each odd-numbered block using the low power of a compound microscope (43.75X), and all animals observed were picked off. On the freshwater silks only crustaceans were observed. The other zooplankters, mostly rotifers and protozoans, are too small to be retained regularly by the 60 meshes per inch silk, and even the ones that were retained were too small and inconspicuous to be noted during our traverse. The animals that were picked off were identified and the results, converted to individuals per cubic meter, are presented in Tables 6 and 7.

The samples from the St. Lawrence Estuary and the Gulf of St. Lawrence were kindly analyzed by the Edinburgh Oceanographic Laboratory of the Scottish Marine Biological Association. They treated these samples as part of their regular survey of the plankton of the North Atlantic using their standard methods (Colebrook 1960).

An attempt has been made to compare the zooplankton communities sampled during the cruise. While obviously very rough, this comparison has the distinct advantage that the samples, from a wide variety of environments, were all taken by the same method.

It had been planned to attempt to sample the zooplankton communities all the way to Spain with the Recorder. However, the outboard end of the cable parted at the towing eye and the Recorder was lost. Fortunately, it has been possible to obtain substitute data for that part of the unsampled

TABLE 6. The abundance (individuals/m^3) of crustaceans caught by the Continuous Plankton Recorder in a tow in Lake Erie from Pointe aux Pins to off the entrance to the Welland Canal.

Organism	Block No. 1	3	5	7	9	11
Cladocera						
Daphnia galeata mendotae	8056	8616	8296	4104	1224	4416
D. retrocurva	40	120	224	440	80	112
Bosmina coregoni	24	24	24	136	64	32
Diaphansoma brachyurum	40	32	56	72	0	0
Leptodora kindti	16	24	32	48	40	56
Unidentifiable *Daphnia*	320	176	240	56	88	216
Unidentifiable *Bosmina*	8	16	0	16	0	0
Total Cladocera	8504	9008	8872	4872	1496	4832
Cyclopoida						
Cyclops bicuspidatus adults	192	208	400	480	24	128
Mesocyclops edax adults	232	680	1160	704	80	160
Cyclopoid copepodids	448	640	1048	784	48	240
Unidentifiable Cyclopoida	0	0	0	8	0	8
Total Cyclopoida	872	1528	2608	1976	152	536
Calanoida						
Diaptomus oregonensis adults	232	680	1032	712	144	160
D. ashlandi adults	24	8	0	8	0	8
D. siciloides adults	72	104	96	40	8	0
D. minutus adults	0	0	0	8	0	0
Diaptomid copepodids	120	352	208	184	16	56
Unidentifiable diaptomids	32	56	48	0	8	0
Eurytemora affinis	0	0	8	0	0	0
Total Calanoida	480	1200	1392	952	176	224
Miscellaneous						
Cladocera embryos	8	24	40	8	0	0
Nauplii	0	0	0	0	0	8
Total Miscellaneous	8	24	40	8	0	8
Total all Crustaceans	9864	11760	12912	7808	1824	5600

TABLE 7. The abundance (individuals/m^3) of crustaceans caught by the Continuous Plankton Recorder in a tow in Lake Ontario from off the entrance to the Welland Canal to the entrance to the St. Lawrence River.

Organism	Block No.							
	1	3	5	7	9	11	13	15
Cladocera								
Daphnia galeata mendotae	32	8	8	0	8	16	0	168
D. retrocurva	24	80	8	8	88	118	160	440
Bosmina coregoni	72	32	16	8	0	0	0	32
B. longirostris	16	8	0	0	0	0	0	0
Leptodora kindti	16	16	0	0	8	0	24	24
Unidentifiable *Daphnia*	8	0	0	0	0	0	0	24
Unidentifiable *Bosmina*	24	16	0	0	0	0	16	24
Total Cladocera	192	160	32	16	104	134	200	712
Cyclopoida								
Cyclops bicuspidatus adults	64	0	16	8	16	8	0	0
Cyclopoid copepodids	80	0	8	0	0	0	0	16
Total Cyclopoida	144	0	24	8	16	8	0	16
Calanoida								
Diaptomus oregonensis adults	80	8	0	0	0	0	0	0
Diaptomid copepodids	56	8	0	8	0	0	0	0
Eurytemora affinis	0	0	0	0	0	32	8	40
Total Calanoida	136	16	0	8	0	32	8	40
Miscellaneous								
Cladocera embryos	8	0	8	8	16	0	0	16
Nauplii	0	0	0	0	0	0	8	0
Total Miscellaneous	8	0	8	8	16	0	8	16
Total all Crustaceans	480	176	64	40	136	174	216	784

cruise path up to the North Atlantic Drift. Recorder tows were made south of Newfoundland, over the Grand Banks, and east of the Grand Banks within two weeks of our cruise as part of the Edinburgh Laboratory's routine survey. These data have kindly been made available by that laboratory and have been included in the comparison.

The abundance values in the data from the Edinburgh Laboratory are only approximate. In their survey the abundance of an organism is estimated only as far as a series of abundance ranges (Colebrook 1960). However, Rae (1952) has calculated a mean number for each of the ranges based on actual counts, and these values have been taken as the abundance values for the purposes of the present paper.

As a measure of diversity, the mean numbers of microcrustacean species and of all zooplankter species per block have been calculated for each environment (Table 8). Only the zooplankters large enough to be retained reasonably well by the 60 meshes per inch silk have been included. The values from the marine environment may be somewhat underestimated because the routine Recorder survey does not identify down to the species level in most cases. Long experience with Recorder samples from the North Atlantic has shown that, in most cases, only one species is present on a block from any one of the groupings used in the identifications and it is believed that we can consider the underestimation as relatively minor.

It will be noted that the freshwater environments have more species than the marine. This is somewhat surprising for it is usually assumed that diversity is less in fresh water. This rather anamolous situation probably is caused to some extent by the paucity of plankton species found in the upper waters of the North Atlantic compared to most other marine areas. There seems little doubt that many more species are present in the North Atlantic at other depths than those sampled, and this is almost assuredly

TABLE 8. The mean number per block of species of microcrustacea and of total zooplankton species as well as the mean abundance per block of microcrustacea and of total zooplankton (individuals/m^3) from a number of environments sampled by the Continuous Plankton Recorder.

Environment	Species of micro-crustacea	Total species of zooplankton	Abundance of micro-crustacea	Total abundance of zooplankton
Lake Erie	9.5	9.5	8295	8295
Lake Ontario	4.9	4.9	259	259
St. Lawrence Estuary	1.2	1.4	20	20
Gulf of St. Lawrence	1.9	3.4	111	113
South of Newfoundland	2.1	3.1	67	92
Grand Banks	1.7	3.8	35	139
East of Grand Banks	1.0	1.9	25	31

not true in the lakes. These results do suggest that caution should be exercised in assuming marine environments are more diverse in species than comparable freshwater ones.

The mean abundance of microcrustaceans and of all zooplankters per block has also been calculated for each environment (Table 8.) The most outstanding fact is the tremendous abundance of zooplankton in Lake Erie compared to all the other environments. This may be attributable to high phytoplankton productivity in this lake as suggested by the high particulate organic matter values found in its western end. This high phytoplankton production would furnish the food for large numbers of zooplankters.

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[1] The asterisk indicates papers already published from this project.

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13. ABSTRACT

This report summarizes the results obtained from a study on the abundance, distribution, and biology of plankton in Lake Michigan as well as from a Research Ships of Opportunity cruise.

Modifications needed to adapt the Continuous Plankton Recorder for use in the Great Lakes are presented in detail. The major change from the procedure used in the marine Recorder survey on the plankton of the North Atlantic is the use of a finer silk for filtering.

A detailed presentation is also made of the scientific results obtained during a cruise aboard a Research Ship of Opportunity from Detroit, Michigan to Bilboa, Spain. Studies were made on the changes in composition of the zooplankton community as well as in the amounts of particulate organic matter and dissolved organic matter encountered during this cruise. The diversity and quantity of microcrustaceans were found to be greater in the lakes than in the comparable marine environments. Particulate and dissolved organic matter followed very similar trends in relative abundance and were especially high in western Lake Erie and at the mouth of the St. Lawrence River.

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